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HEAT-TRANSFER TESTS OF A STEEL CYLINDER BARREL WITH ALUMINUM FINS OF OPTIMUM PROPORTIONS

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for the

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INTRODUCTION

At the request of the Bureau of Aeronautics, Navy Department, an engine cylinder barrel with aluminum fins was tested by this laboratory (reference 1). Later two more barrels manufactured by a method to be used in the factory production of large numbers of engines were tested (reference 2). The tests showed that the thermal bonds between the aluminum fins and the aluminum base and between the aluminum base and the steel for all three barrels were very good. In addition, other tests showed that the mechanical bonds between the cylinder parts would probably be satisfactory.

Based on the results of tests on a large number of finned cylinders, an analysis of optimum fin proportions has been made (reference 3). From this analysis it was predicted that the heat transfer of the barrels reported in references 1 and 2 could be appreciably increased by changing the fin space from about 0.052 inch, the spacing used on the three barrels tested, to 0.090 inch. The amount of increase, for instance, was about 19 percent for the cylinder described in reference 1.

As a result of the foregoing analysis a steel cylinder barrel with aluminum fins of the optimum spacing of 0.090 inch was made and the results of tests on this cylinder are given in the present report. The purpose of the tests was to determine the excellence of the thermal bonds between the aluminum fins and the aluminum base and between the aluminum base and the steel and to compare the heat transfer of this barrel with that of the barrels with a fin space of 0.052 inch. Tests were also made to determine the adequacy of the mechanical bonds between the fins and the aluminum base and between the aluminum base and the steel. The tests were made at the request of the Bureau of Aeronautics, Navy Department.

APPARATUS AND METHODS

The apparatus and methods used for testing the present cylinder barrel were similar to those used to test the two barrels reported in reference 2. The fin spacing of the barrel reported herein was 0.090 inch; the fin width, 0.375 inch; and the fin thickness, 0.026 inch. The barrel reported in reference 1 had a fin space of 0.052 inch, a fin width of 0.375 inch, and a fin thickness of 0.025 inch. The two barrels of reference 2 had fin widths of 0.438 inch, fin spaces of 0.052 inch, and fin thicknesses of 0.025 inch. The effect of fin space on heat transfer is determined in the present report by comparing the results of the tests on the two barrels with 0.375-inch fin width. These two barrels are shown in figure 1. The flange of the 0.090-inch space cylinder was cut off to facilitate installation in the heat-transfer apparatus.

RESULTS AND DISCUSSION

Heat-Transfer Tests

The surface heat-transfer coefficients q of finned cylinders have been correlated, as noted in reference 1, for an air-flow arrangement as used in the present tests (reference 4). Thus, it has been found for cylinders enclosed in a jacket and cooled by a blower,

$$\frac{qs}{k_a} = f\left(\frac{V\rho_1 gs^2}{12\mu\, D^{0.25}}\right) \tag{1}$$

where

q surface heat-transfer coefficient, Btu per square inch fin surface area per °F difference between the average temperature of the cooling surface and the entering-air temperature per hour

s average space between fins, inches

k_a thermal conductivity of the cooling air, But per square inch per °F per second through 1 inch

$V\rho_1 g$ the weight velocity of the cooling air pounds per second per square foot of free flow area between the fins

μ absolute viscosity of the cooling air, pounds per second per foot

D diameter of cylinder at fin root, inches

Figure 9 (d) of reference 4 shows a curve established from tests on a large number of cylinders with an air-flow arrangement as in the present tests, plotted in terms of functions of equation (1). Surface heat-transfer coefficients for a cylinder with fin and cylinder dimensions the same as for the test cylinder were calculated from this curve for several weight velocities between the fins. The results are shown in the curve marked "calculated coefficients" in figure 2. The experimental surface heat-transfer coefficients for the test cylinder are also shown in figure 2.

The experimental coefficients are appreciably greater than the calculated coefficients. The tests were repeated twice, and the setup completely checked. The experimental over-all coefficients U were also much greater than the calculated over-all coefficients for the cylinders reported in references 1 and 2. It was thought, in the case of the cylinders in these references, that the difference was due in part to the fact that no greater accuracy than that obtained could be expected when comparing the results of any one cylinder with results calculated from a correlation curve. The results of figure 2 are too far apart for this reasoning to be applicable.

The experimental surface heat-transfer coefficients of the cylinder reported in reference 1, one of the cylinders reported in reference 2, the present cylinder, and a steel cylinder with integral fins of short width have been plotted in figure 3 in terms of the functions of equation (1). Also plotted on the figure is the curve of reference 4 which has been used in references 1 and 2 and in figure 2 of the present report to determine calculated coefficients. A new curve can be drawn through the data of the cylinders with short fins that is appreciably higher than the old curve. Reference to figure 9 (d) of reference 4 shows that some points for cylinders with short fins were much higher than the faired curve that was drawn through the experimental points of all the cylinders tested. From the results of figure 3 it is concluded that the old correlation curve is not applicable to cylinders with short width fins. Equation (1) shows that fin width does not enter into the correlation, only fin spacing. For large widths the fin spacing is the predominating fin dimension in heat transfer, this case being analogous to heat transfer between two flat plates. For small fin widths, however, the case is more analogous to flow through tubes and channels and the functions of equation (1) should probably involve an equivalent diameter instead of fin space. Further effort to correlate data of cylinders with fins of various widths is needed.

The experimental over-all heat-transfer coefficients for various pressure differences for the present cylinder and the cylinder reported in reference 1 are shown in figure 4. The only difference in the cylinders, as previously stated, is the fin spacing. As mentioned in the introduction, the results of the analysis to determine the effect of changing the fin space from 0.052 to 0.090 inch, using aluminum fins, are given in figure 5. The calculations are based on a fin width of 0.375 inch and a fin thickness of 0.025 inch, the fin dimensions of the first barrel tested. The results of figure 4 check the results of figure 5 in that the cylinder with 0.09-inch space showed a higher heat transfer than the 0.052-inch fin space cylinder. At 8 inches of water pressure difference, for instance, the increase in heat transfer is approximately 26 percent based on the heat transfer of the 0.052-inch space cylinder. The curves of figure 4 are higher than the corresponding curves of figure 5 for the same pressure difference, for the reasons given in the discussion of figure 3, but the difference in heat transfer between the two cylinders on either figure is approximately the same. The coefficients of the 0.09-inch fin space cylinder based on either the temperature of the steel or the temperature of the aluminum base were approximately the same, as shown in figure 4. This agreement indicates that the thermal bond between the steel and aluminum base is satisfactory.

The fin width of the barrels reported in reference 2 was 0.438 inch and that of the barrel reported in reference 1 was 0.375 inch, as previously noted. It was shown in reference 2 that with this increase in fin width, at a given weight velocity, the over-all heat-transfer coefficient increased approximately 15 percent. Figure 6 shows the experimental over-all heat-transfer coefficients of the four barrels for various pressure differences. The greatest heat transfer was obtained from the cylinders with 0.438-inch fin width even though their fin spacing was only 0.052 inch, indicating the importance of fin width. The additional fin width, as compared with the 0.375 inch width, was more than sufficient to overcome the loss in heat transfer that occurred because the fin space was not 0.09 inch. It is estimated that the heat transfer of the cylinder herein reported could be increased approximately 35 percent, or U would be about 1.96 Btu per °F per square inch per hour at a pressure difference of 8 inches of water, by increasing the fin width from 0.375 to 0.438 inch.

Thus, with a steel barrel with aluminum fins of 0.09-inch fin spacing and 0.438-inch fin width approximately 87 percent more heat transfer should be obtained as compared with a steel barrel with steel fins of 0.052-inch spacing and 0.375-inch fin width. It is not necessary to test a barrel with optimum fin spacing and wider fins than are on the present cylinder to check the foregoing estimates, as the effect is well brought out in figure 6 with the 0.052-inch fin space cylinders.

Physical Tests

The tests to determine whether the mechanical bonds between the fins and the aluminum base and between the steel and the aluminum base were satisfactory were similar to the tests made on the other three barrels previously tested. The barrel was cut in half, one half was cut in quarters, and about an inch of one quarter was cut off. One edge of the quarter piece was polished and etched, and the result shown in figure 7. The outline of the fins did not show up as well as on the previous cylinders, except for the two end fins, although the time of etching was greater for the present barrel than for the other barrels. This result would indicate that the bond between the fins and the aluminum base was good but such was not the case. The bond was worse than any barrel that has been tested. When the barrel was received some of the fins could be worked back and forth in their grooves. Also the fins could be easily pulled from their grooves with pliers on the 1-inch piece cut from one quarter. A similar test on a 1-inch piece from a former barrel showed that no amount of pulling could dislodge the fins. It can be concluded that the mechanical bond between the fins and aluminum base of the present barrel was very poor.

The steel was then pried loose from the aluminum base of the half section of the barrel. The force required to remove the steel from the aluminum base was much greater than in similar tests of former barrels and it can be concluded that the mechanical bond is satisfactory. There seemed to be more mixing of the flux material with the aluminum and the steel with the present barrel than with the former barrels as shown in figure 8, which shows the two sections, steel and aluminum base, of the half piece after they had been pried apart. It has been noticed, however, in all the barrels that there did not seem to be a chemical mixing of the aluminum in the steel or of the steel in the aluminum. The bond seems to be more analogous to the case of the pasting of two pieces of paper together.

CONCLUSIONS

1. The over-all heat-transfer coefficient of the present barrel with a fin spacing of 0.09 inch was approximately 26 percent greater than the coefficient of the 0.052-inch fin space barrel at 8 inches water pressure difference.

2. Heat-transfer tests indicated that the thermal bonds between the aluminum fins and the aluminum base and between the aluminum base and the steel are very good.

3. Tests showed that the mechanical bond between the fins and the aluminum base was very poor.

4. The mechanical bond between the steel and aluminum base was a little better than for the other barrels tested and is considered satisfactory.

5. The bonding of the steel to the aluminum base does not seem to be a chemical bonding but is more analogous to the case of pasting two pieces of paper together.

6. The addition of fin width to the present barrel, if practical, should increase the heat transfer appreciably. An increase of 1/16 inch, for instance, would increase it about 35 percent.

7. From the results of the present tests and calculations it is estimated that the heat transfer of a steel cylinder barrel with fins of 0.052 inch space and 0.375 inch width could be increased 87 percent if aluminum fins of 0.09 inch space and 0.438 inch width were used.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 13, 1940.

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2. Ellerbrock, Herman H., Jr.: Heat-Transfer Tests of Two Steel Cylinder Barrels with Aluminum Fins Manufactured by Factory Production Method. NACA Memo. Rep., Aug. 12, 1940.

3. Biermann, Arnold E., and Ellerbrock, Herman H., Jr.: The Design of Fins for Air-Cooled Cylinders. NACA Rep. No. 726, 1941.

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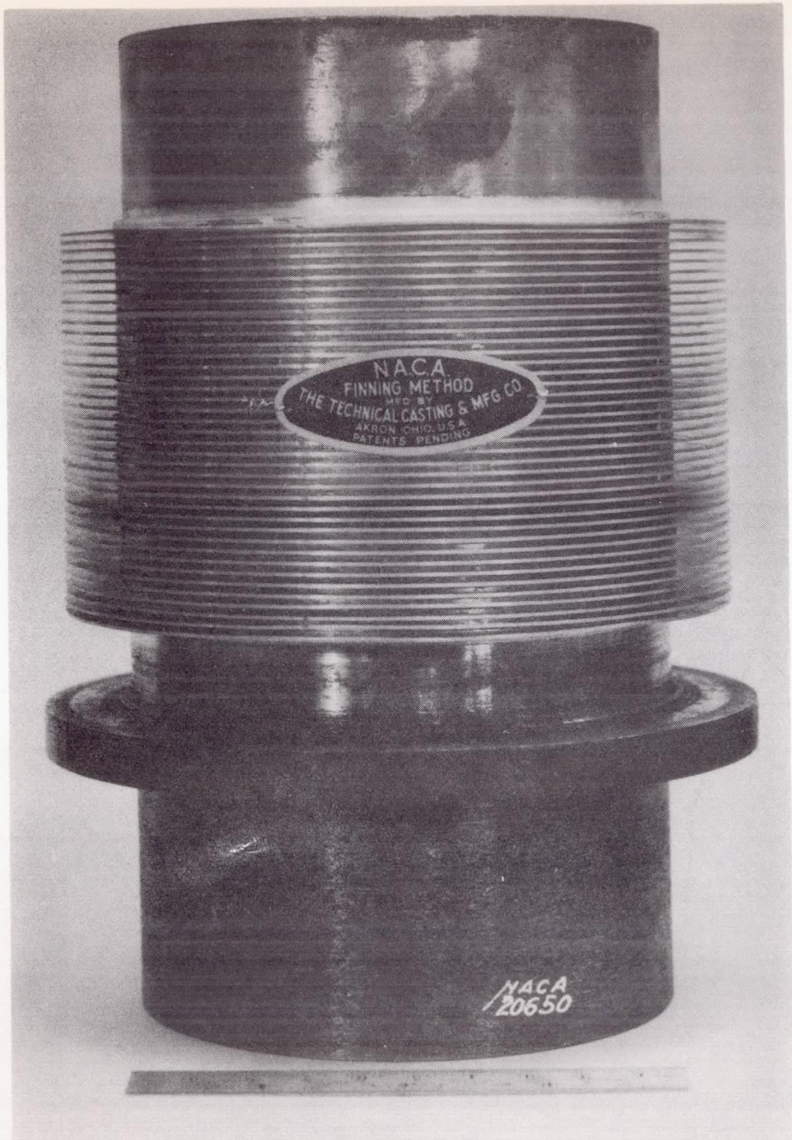
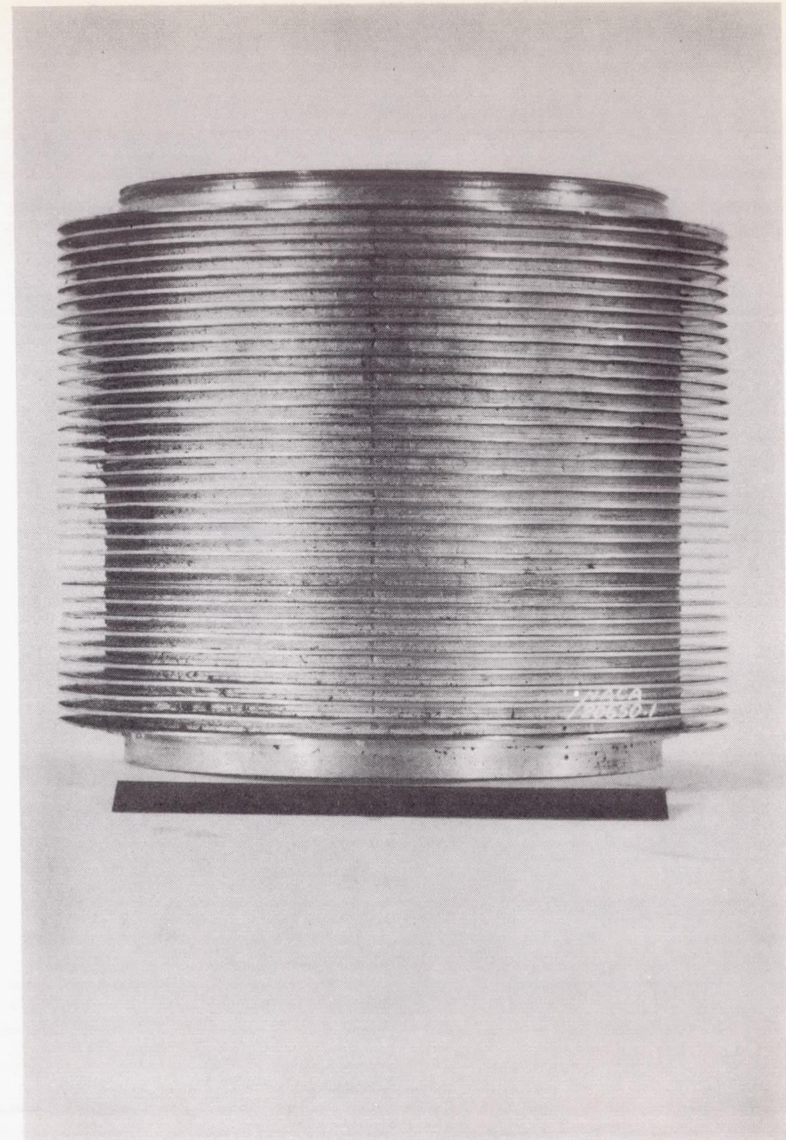


(a) Barrel with 0.052-inch fin space.



(b) Barrel with 0.09-inch fin space.

Figure 1. - Engine cylinder barrels.

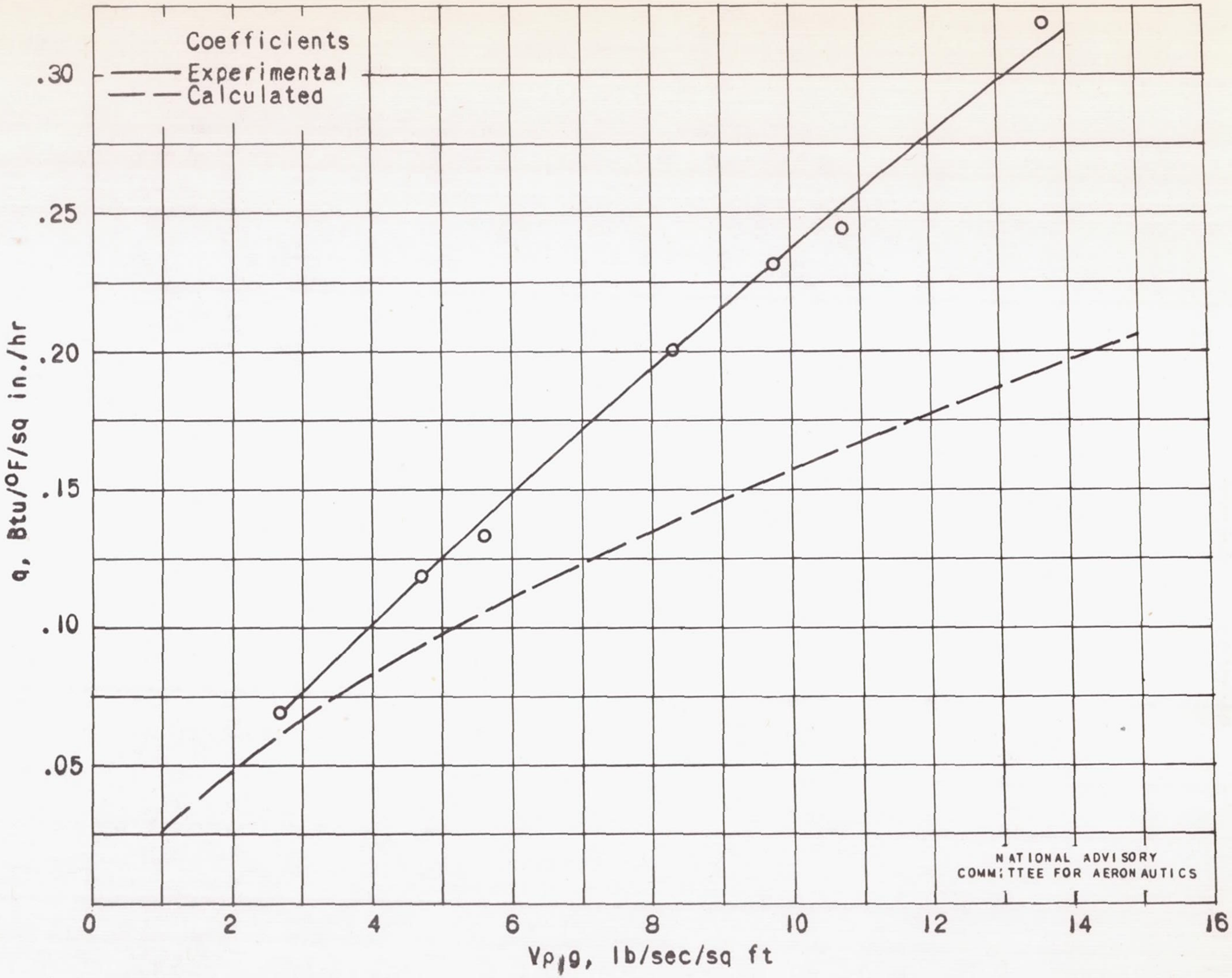


Figure 2. - Comparison of experimental and calculated surface heat-transfer coefficients for cylinder 4.

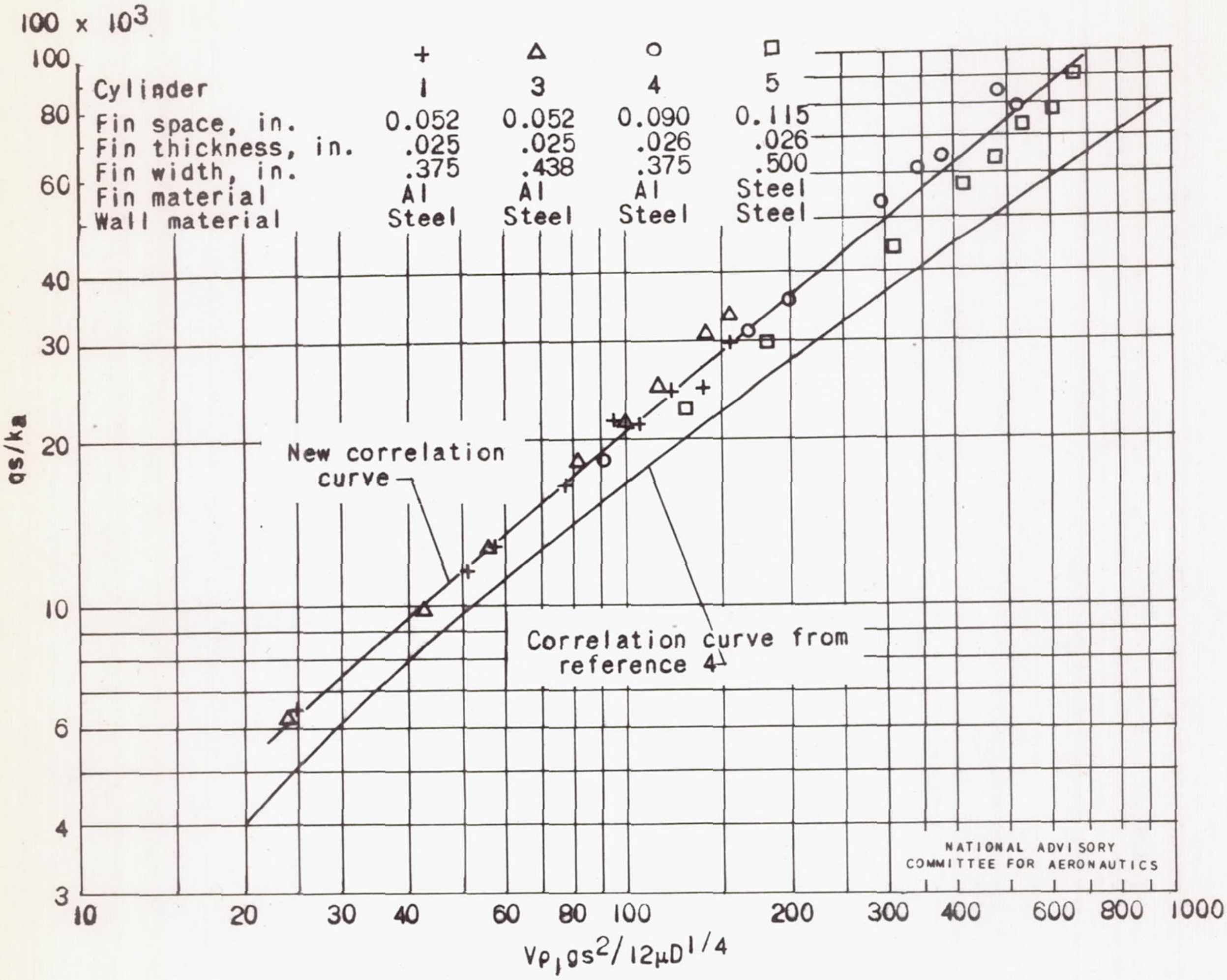


Figure 3. - Relation between factors involving q, fin dimensions, cylinder diameter, and air-stream characteristics.

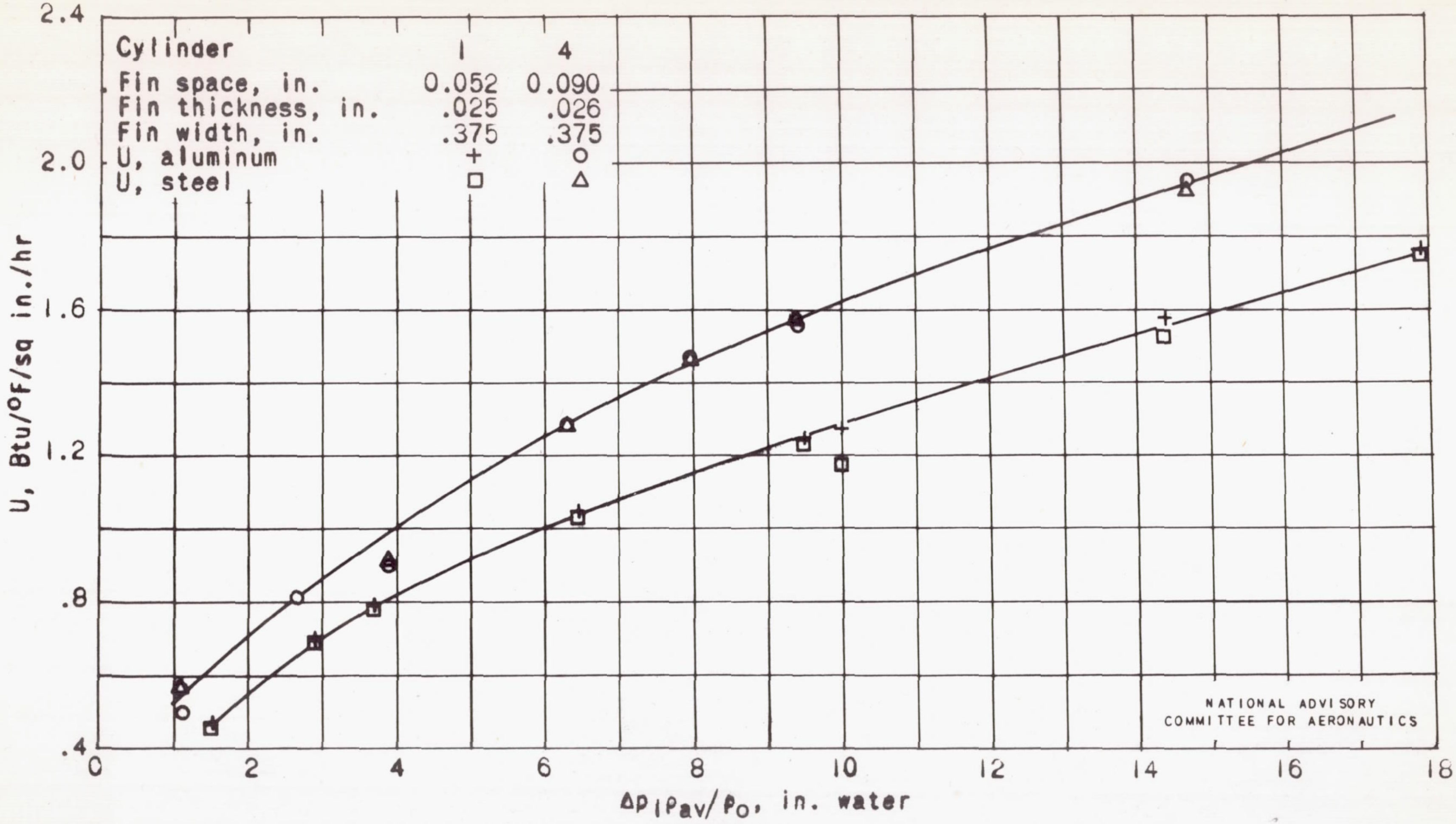


Figure 4. - Comparison of experimental over-all heat-transfer coefficients for cylinders 1 and 4.

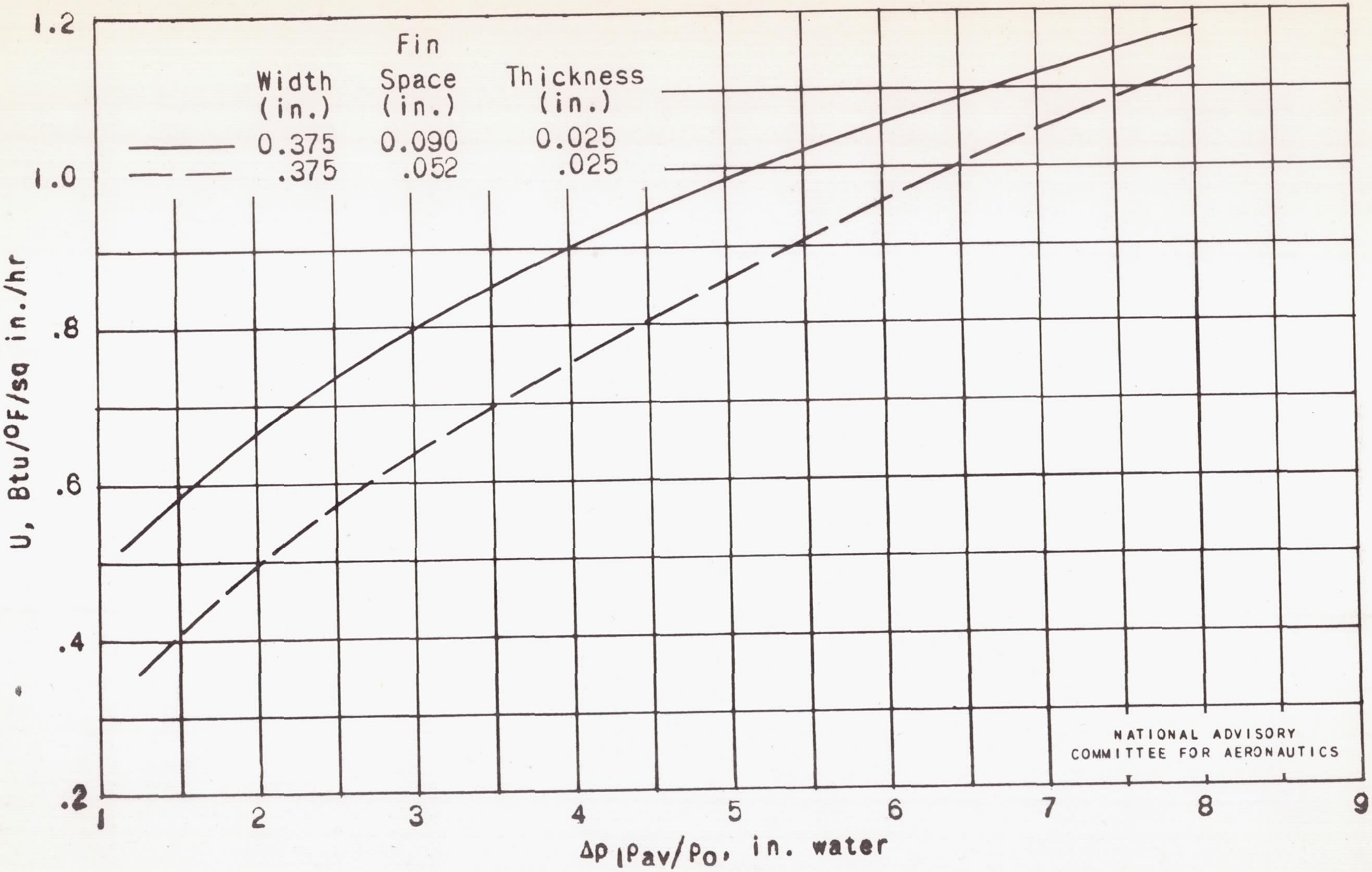


Figure 5. - Comparison of calculated over-all heat-transfer coefficients of two aluminum cylinders with aluminum fins.

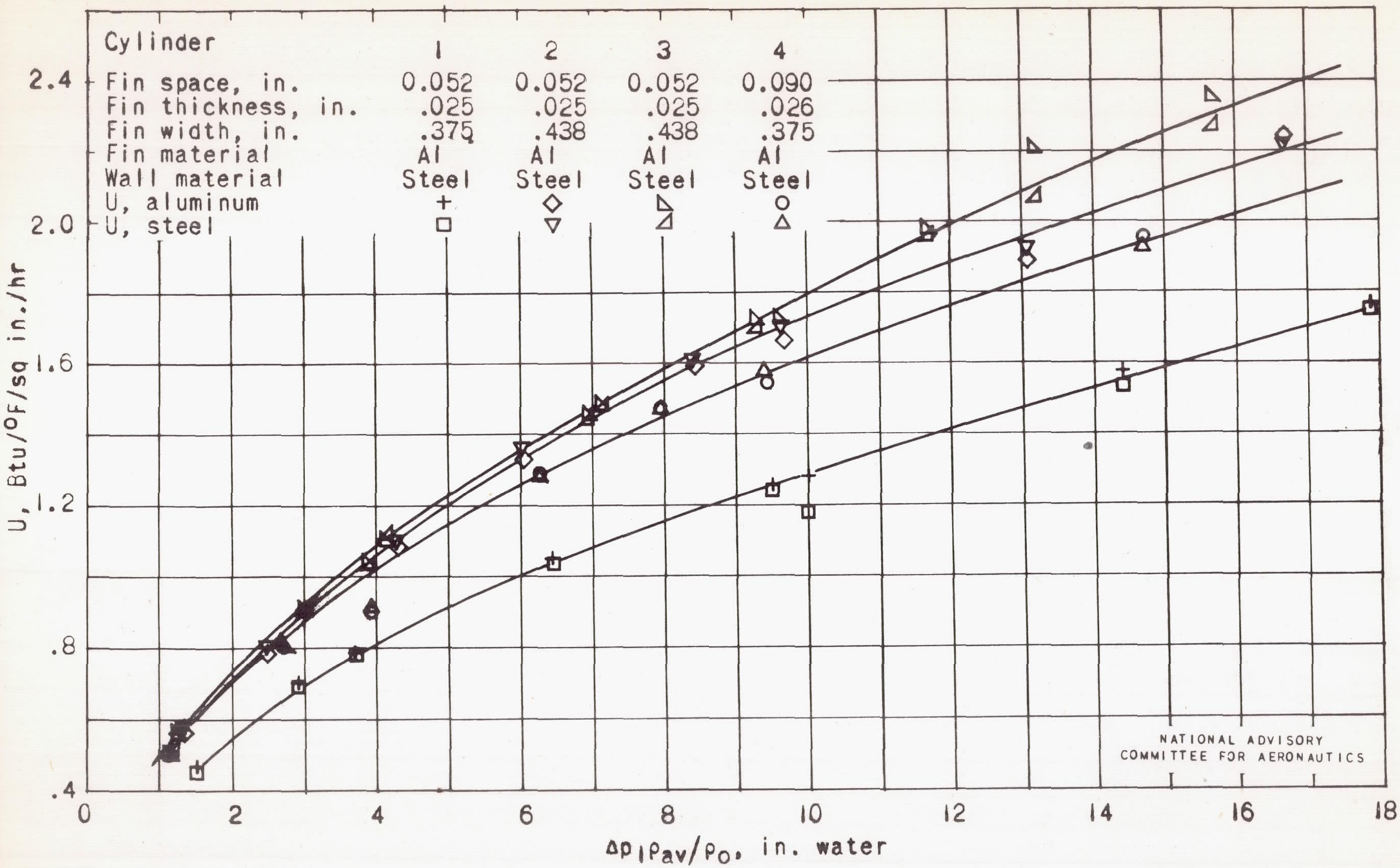


Figure 6. - Comparison of the experimental over-all heat-transfer coefficients of the four cylinder barrels.

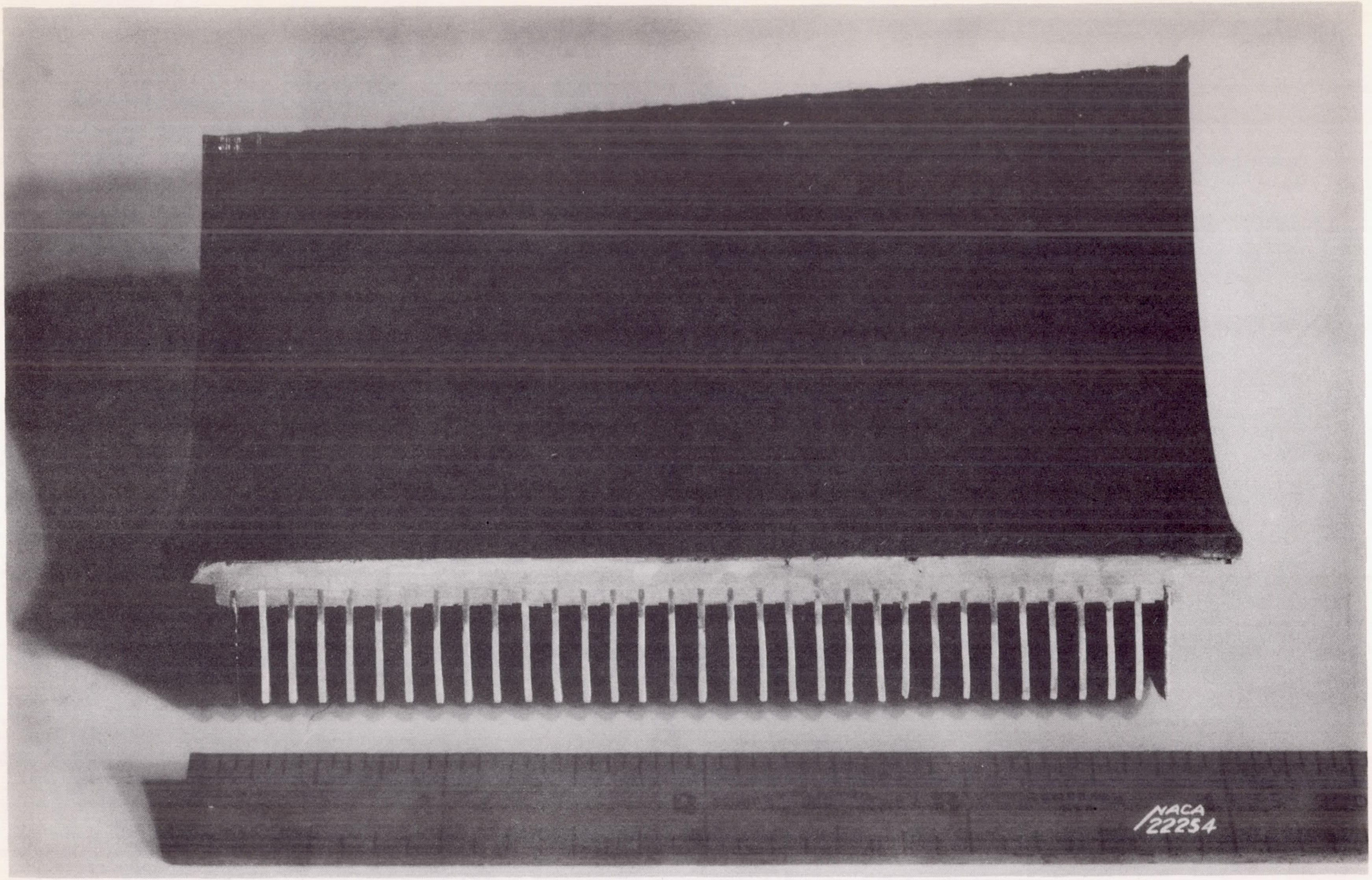


Figure 7. - Polished and etched section of cylinder showing fin outline.

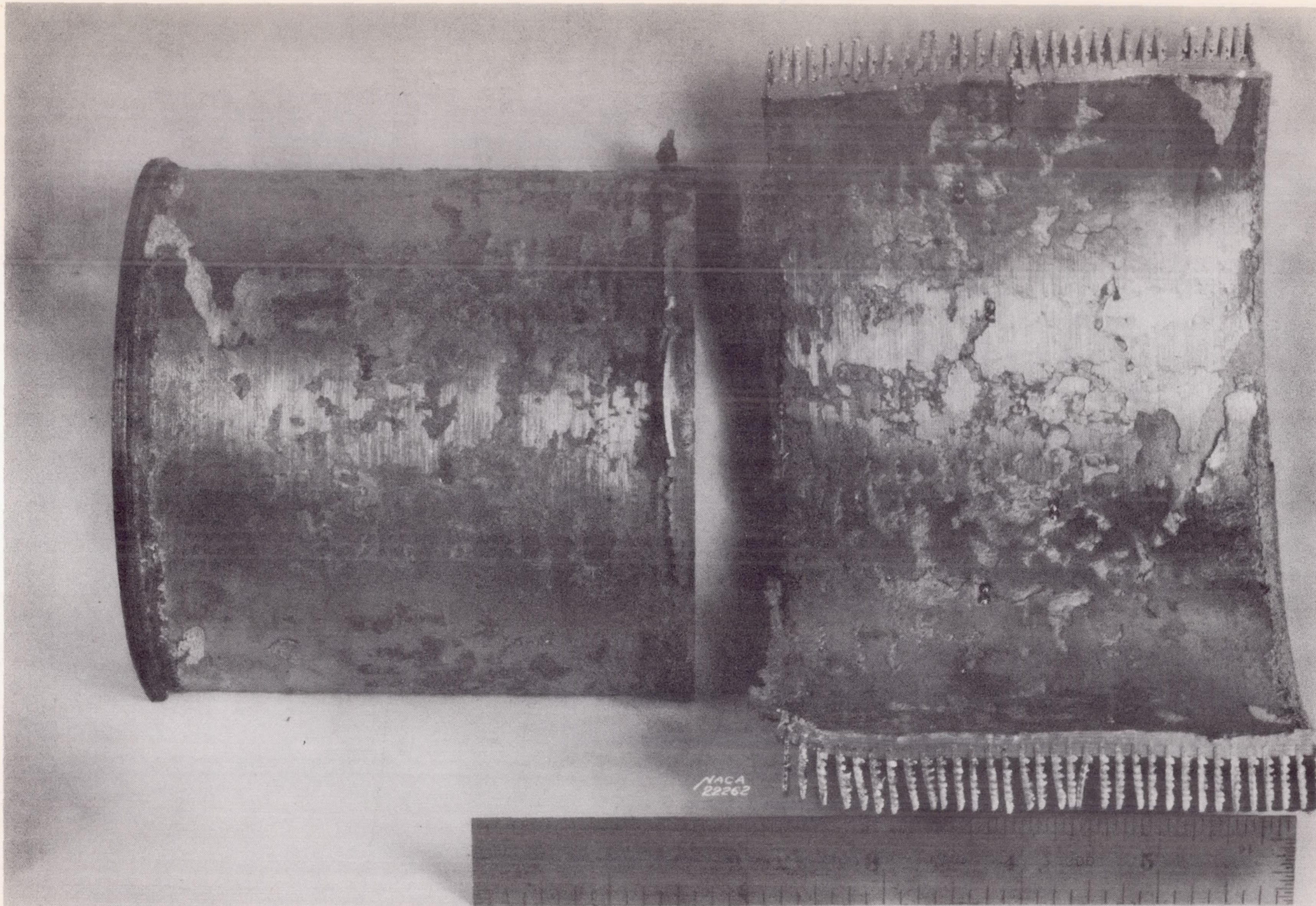


Figure 8. - Half section of cylinder after steel was pried from aluminum base.